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Parametric Insurance for Solar Geoengineering: Insights from the Pacific Catastrophe Risk Assessment and Financing Initiative

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Abstract

Solar geoengineering (SG) entails using technology to modify the Earth's radiative balance to offset some of the climate changes caused by long-lived greenhouse gases. Parametric insurance, which delivers payouts when specific physical indices (such as wind speed) cross predefined thresholds, was recently proposed by two of us as a compensation mechanism for SG with the potential to ease disagreements about the technology and to facilitate cooperative deployment; we refer to this proposal as reduced-rate climate risk insurance for solar geoengineering, or 'RCG'. Here we probe the plausibility of RCG by exploring the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), a sovereign risk pool providing parametric insurance coverage against tropical cyclones and earthquakes/tsunamis to Pacific island countries since 2013. Tracing the history of PCRAFI and considering regional views on insurance as compensation necessitates reconfiguring RCG in a way that shifts the focus away from bargaining between developed and developing countries toward bargaining among developed countries. This revised version of RCG is challenged by an assumption of broad developed country support for sovereign climate insurance in the developing world, but it also better reflects the underlying incentive structure and distribution of power.

Policy Implications

- For parametric insurance to serve as a compensation mechanism for solar geoengineering, regional experiences, views, and understandings must be taken into account.
- The record of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) risk pool combined with Pacific regional climate politics (including emerging views on solar geoengineering) provide such a perspective.
- Pacific regional views suggest that for insurance to be viewed as compensatory, premiums must be subsidized by developed countries, and coverage must be new and additional to conventional disaster risk insurance.
- This perspective indicates that, at least in the Pacific, linking parametric insurance and solar geoengineering would depend primarily on bargaining among developed countries divided over whether to deploy the technology, rather than on bargaining between developed and developing countries.

Introduction

Solar geoengineering (SG; also referred to as solar radiation management or solar radiation modification – SRM) is increasingly being discussed as a possible policy complement to greenhouse gas (GHG) emission reductions (mitigation), carbon removal, and adaptation. SG would entail enhancing the albedo (reflectivity) of the Earth, for instance by adding aerosols to the stratosphere or brightening clouds, in order to reflect a small fraction of incoming sunlight back to space and thereby counteract some of the effects of climate change. The potential of SG to limit climate risks depends on its ability to reduce key climate hazards such as extreme temperatures, tropical cyclone intensity, or sea level rise on a regional basis. Evidence from a suite of global climate models suggests that if SG is applied in a spatially uniform way in combination with emissions reductions to reduce but not eliminate temperature rise, then it can reduce many, perhaps most, important climate hazards in most regions without leaving any major regions worse off (Irvine et al., 2019; Irvine and Keith, 2020; Kravitz et al., 2013; Moore, et al., 2015).

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Yet research to date shows unequivocally that SG cannot reduce all hazards equally, and that unequal application of SG can produce highly unequal climate changes inducing significant risks (e.g., Jones et al., 2017). Among these risks, researchers have paid most attention to the possibility of regional hydrological changes that may cause flooding and droughts (e.g., Tilmes et al., 2013). Deployment of SG, therefore, would need to be supplemented with a credible mechanism for compensating victims in the event such risks materialize.

Recently, parametric insurance, in which payouts are tied to objective environmental indicators, has been advanced as a potential compensation mechanism for SG. With parametric insurance, policies specify a physical index (like rainfall) and a value of that index above or below which a payout is automatically triggered according to the terms of the insurance contract. The index serves as a proxy for a particular peril (like flooding), and the payout is intended to compensate the policyholder without the need for a loss assessment. When applied to harms from climate change, parametric insurance is known as climate risk insurance (CRI).

Parametric insurance initially gained prominence as a form of disaster risk management (DRM), and more recently has become central in discussions of loss and damage (L&D) from climate change, where there is growing attention to the potential compensatory role of CRI (Schinko et al., 2019). In this regard, parametric insurance appears to have structural advantages compared to conventional liability, including sidestepping issues of causation and attribution (Horton, 2018). But parametric insurance has limits. It entails basis risk, or the risk that index measurements fail to correspond to actual loss. Parametric insurance does not offer protection against damaging long-term trends like sea level rise that are not punctuated by discrete events (McGee et al., 2014). And insurance (including parametric) is expensive compared to other forms of disaster risk finance and best suited to low-frequency, high-impact events; ideally, different instruments should be applied to different risks using a risk-layering approach (Clarke et al., 2017).

The idea of using parametric insurance in the form of CRI as a compensation mechanism for SG is premised on recognizing that significant uncertainty is inherent in the climate response to SG and in attributing that response.[1] This is likely to give rise to disagreements. The proposed use of CRI for SG specifies two types of countries, 'proposing' states (essentially developed countries) interested in deploying SG and 'opposing' states (essentially poor or middle-income countries) set against deployment. The proposal also specifies two types of insurance, 'business as usual (BAU)' or conventional CRI, and coverage that is identical to BAU insurance but guaranteed at a reduced rate (RR) relative to BAU by proposing states. RR insurance would be based on the expectation of reduced climate harms – and hence lower premiums – under a moderate SG deployment. But proposing states would offer RR insurance only to states that consent to deployment.

Given this choice, opposing states would face three possible outcomes: (1) they could reject the offer and purchase BAU insurance at increasingly higher rates as climate change worsens; (2) they could purchase RR insurance, and if SG failed to work they would receive compensation as well as cost savings compared to BAU; or (3) they could purchase RR insurance, and if SG succeeded they would benefit from reduced climate risks as well as cost savings compared to BAU. Since RR insurance would leave opposing states better off compared to BAU *regardless of whether SG works*, opposing states would be incentivized to buy it and at least tacitly accept deployment (for more details, see Horton and Keith, 2019). In what follows, we refer to this proposal as *r*educed-rate climate risk insurance for solar *g*eoengineering, or 'RCG'. One of the more important advantages of RCG is that the negotiations it would entail would help bring into focus specific concerns held by opposing countries about SG, enhancing transparency and drawing out potential bases for cooperation.

The abstract nature of the RCG argument allows for delineating the essential features of a possible international bargain on SG. Further developing this proposition, however, requires calibrating the ideas behind RCG against the empirical record of parametric insurance. One methodologically sound way to do this involves conducting a 'plausibility probe' case study to validate theory using detailed knowledge from one particular historical episode (Eckstein, 1992).

The purpose of this article is to assess the plausibility of RCG, and revise it where necessary, by exploring the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI). Since 2013, a number of Pacific island countries (PICs) have purchased – and received payouts from – parametric insurance policies covering tropical cyclones and earthquakes/tsunamis offered by PCRAFI financing instruments.[2] We have chosen PCRAFI because it is one of only three regional parametric sovereign climate risk pools in existence (the others operate in the Caribbean and Africa), and because its Pacific regional setting places it in the 'front line' of climate change and climate politics in a way that is unique compared to these other regions and has involved participating countries and affiliated bodies taking center stage in global debates on L&D.

By examining PCRAFI and related regional discussions about L&D, we identify an important way in which RCG must be reconfigured if it is to have practical relevance to the Pacific: given PIC views on the conditions under which insurance functions as compensation, RCG must be reconceived around a central bargain between developed countries supporting and opposing SG deployment. This rethinking presents challenges insofar as its rests on a background assumption of industrialized state support for CRI, but it also brings RCG into closer alignment with Pacific regional politics as well as the emerging international politics of SG. Whether or not this finding extends beyond the Pacific depends on the degree to which other regions' experiences with CRI and L&D resemble those in the Pacific, and the implications of those experiences for industrialized countries.

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We proceed as follows. We begin with a summary of climate risks in the Pacific and the limited preliminary research on SG in the region. We then describe the origins, design, and record of PCRAFI. Next, we consider how Pacific regional actors regard insurance in the context of wider debates about compensation for climate damages. We then reconsider RCG in light of the Pacific regional experience with parametric insurance and climate policy and make an important revision to the argument as it applies to the Pacific. We end with a conclusion.

Climate risks and solar geoengineering in the Pacific

Due to their geographic location and development status, PICs rank among the most disaster-prone countries in the world (World Risk Reports, 2018). Yet climate impacts in the Pacific vary widely in magnitude, frequency, and spatial extent, and their severity depends on both the biophysical nature of islands and their social, economic, and political settings (Nurse et al., 2014). Impacts fall into two broad categories based on temporal scale, with extreme weather events such as tropical storms occurring over roughly a day, whereas secular ('slow-onset') changes such as sea level rise unfold over a century.

The dominant mode of climate variability in the Pacific region is the multi-year, quasi-periodic El Niño Southern Oscillation (ENSO), the pattern of alternating warming and cooling of sea surface temperatures (SSTs) in the central and eastern equatorial Pacific. The 'warm' phase is known as El Niño and the 'cold' phase as La Niña. ENSO is an important driver of global-scale climate variability. In the Pacific region, ENSO manifests in the form of precipitation anomalies (droughts and floods) and changes in the distribution of tropical cyclones.

While there is no consensus about the overall response of ENSO to anthropogenic climate change, there is evidence that ENSO-related variability will increase and with that the frequency of extreme events (Cai et al., 2014, 2018). There is no doubt that sea level will rise, but the rate of rise this century is deeply uncertain due to the low-probability high-consequence 'tails' of the probability distribution stemming from the possibility of significant contribution from West Antarctica or Greenland. On its own, sea level rise poses serious – in some cases, existential – risks to low-lying PICs, many of which are atolls, leading to deep concerns about territorial loss, population displacement and resettlement, and other severe climate impacts. Combined with tropical cyclones, sea level rise will mean higher storm surges and hence greater damage to ecosystems, infrastructure, and other economic assets.

Very little scientific research has focused specifically on how SG might affect PICs. In an important early study, MacMynowski (2009) found that regional cooling via SG has the potential to dampen El Niño and reduce associated extreme weather events. This study explored whether marine cloud brightening (to enhance the reflectivity of the marine boundary layer) could be used to reduce SSTs in the Eastern Pacific so as 'to intentionally influence the dynamics of ENSO in order to reduce (or enhance) the probability of extreme El Niño events'. Modeling results from this analysis show that '[t]he forcing required is of a scale achievable by human intervention, and seems plausible if cloud albedo modification were being used to offset some global warming'. Multiple climate modeling studies show that SG would slow the rate of sea level rise (Irvine et al., 2016). Finally, and perhaps most importantly, several studies show that SG can reduce tropical cyclone intensity (Irvine et al., 2019; Wang et al., 2018).

Only a small amount of research on public perceptions of SG in the region has been conducted. At a workshop held in Suva, Fiji, in 2013, regional stakeholders expressed eagerness to respond forcefully to climate change and openness to SG as one possible response option (Beyerl and Maas, 2014; Lefale and Anderson, 2014). But such openness was accompanied by deep ambivalence and marked discomfort. Participants articulated six specific reasons for concern about geoengineering: (1) lack of knowledge, including about the consequences of abrupt stoppage; (2) the need for precaution; (3) the potential for reductions in mitigation and adaptation caused by talking about, researching, or using SG; (4) a possible slippery slope from research to deployment; (5) the need for inclusiveness; and (6) high uncertainty. A contemporaneous but unconnected set of interviews conducted in the Solomon Islands produced findings very similar to those of the Suva workshop, characterizing local acceptance of SG as 'deeply reluctant and highly conditional' (Carr and Yung, 2018; see also Sugiyama et al., 2020).

One important condition appears to be that compensation is available in case something goes wrong. At the Suva workshop, participants agreed that the 'AOSIS 6 Principles' should serve as the foundation for regulating geoengineering (Beyerl and Maas, 2014).[3] These include the polluter pays principle requiring that parties pay for the cost of damages caused by their pollution (Lefale and Anderson, 2014). Further, when discussions in the Solomon Islands turned to conditions for future use, 'Ultimately, interviewees wanted assurances of accountability for unintended consequences' (Carr and Yung, 2018). As one Solomon Islander put it, 'who is going to be responsible if these things don't go right?' (Carr and Yung, 2018).

The Pacific catastrophe risk assessment and financing initiative (PCRAFI)

In order to reduce their vulnerability and build resilience to a growing array of disaster risks, PICs joined with the World Bank and other partners in 2007 to establish PCRAFI (World Bank, 2016b). PCRAFI was inspired by a parametric-based sovereign risk pool set up in the Caribbean that same year, and was soon joined by another in Africa. Countries participating in PCRAFI included the Cook Islands, the Federated States of Micronesia, Fiji, Kiribati, the Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, the Solomon Islands, East Timor, Tonga, Tuvalu, and Vanuatu.

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PCRAFI was intended to develop a portfolio of DRM tools suitable for use by PICs in preparing for and responding to tropical cyclones and earthquakes/tsunamis; since tropical cyclones are increasing in severity as a result of climate change, PCRAFI was partly envisioned as a climate adaptation strategy. Two key tools were created during the first phase of the project, the Pacific Risk Information System (PacRIS) database compiling regional and national hazard and exposure data, and the PCRAFI Risk Model for calculating disaster risk (World Bank, 2018a). These enabled the production of country risk profiles which served as the basis of the Pacific Catastrophe Risk Insurance Pilot, initiated in 2013.

The purpose behind the Pilot was to offer governments injections of liquidity in the immediate aftermath of natural disasters using parametric insurance. PIC governments were highly constrained in their responses to natural disasters due to a combination of limited budgets and limited access to capital markets. As a result, efforts to rescue, assist, and reestablish basic infrastructure were often inadequate during the critical weeks following an event, and emergency budget reallocations tended to undermine long-term development goals. Speedily disbursed short-term cash infusions were intended to fill this gap. In essence, PCRAFI offered business interruption insurance for governments.

The Pilot was maintained over three consecutive seasons (January–October 2013, November 2013–October 2014, and November 2014–October 2015), roughly coinciding with the tropical cyclone season (World Bank, 2016a). Five PCRAFI countries chose to take part in the first season: the Marshall Islands, Samoa, the Solomon Islands, Tonga, and Vanuatu. Countries selected tropical cyclone and earthquake/tsunami policies based on their preferred 'attachment points' (deductibles) and 'exhaustion points' (maximum coverage). Coverage was for 'emergency losses' incurred by governments following tropical cyclones and earthquakes/tsunamis; based on the historical record, emergency loss was defined as 23 per cent of 'ground-up loss' (total damage to buildings, infrastructure, and cash crops) for tropical cyclones and sixteen per cent for earthquakes/tsunamis (World Bank, 2015a). (Tropical cyclone loss calculations incorporated losses due to both high winds and flooding caused by storm surges and/or excess rainfall.) The Joint Typhoon Warning Center (JTWC) and the National Earthquake Information Center of the U.S. Geological Survey would provide event data ('hazard parameters'). If an event occurred, these data would be entered into 'event footprints' (developed using PacRIS) to model expected losses using the catastrophe risk model; modeled losses would then be compared to predefined triggers to determine whether a payout was required and, if so, how much.

For the first season, the government of Japan fully subsidized premiums ($0.22 million per country), and the World Bank acted as financial intermediary between policyholder governments and the international reinsurance market. Specifically, the World Bank executed index-based 'catastrophe swap' transactions (essentially parametric insurance policies) on behalf of participating PICs with Japanese reinsurers and Swiss Re (and later Munich Re and others). During the second season, all participating countries renewed their policies, each co-financing five per cent of premiums now set at $0.35 million per country (Japan covered the remainder),[4] while the Cook Islands joined the pilot and paid its premium in full.[5] Throughout the project, industrialized country support has been framed as official development assistance (ODA) for disaster risk insurance and climate adaptation, rather than as compensation for L&D.

In January 2014, Tropical Cyclone Ian struck Tonga. Following protocol, the Pilot's third-party 'calculation agent', the catastrophe risk modeling firm AIR Worldwide, used event data to model the expected losses and determined that a payout was triggered, and Tonga received $1.3 million, all within ten days and according to the predefined terms of the insurance contract. This payout amount was equivalent to more than half the country's contingency budget and more than half the reserves in the Tonga National Reserve Fund (PCRAFI Program, 2018).

In 2013, an earthquake struck the Solomon Islands, but because emergency losses were below the attachment point no payout was triggered. Then, in 2014, flooding occurred in the country, but because the JTWC categorized the associated storm as a tropical depression rather than a tropical cyclone (as required by the insurance contract) again no payout was triggered. Although the policies functioned as intended in both cases, the government was disappointed by the lack of payouts and the Solomon Islands left the Pilot (World Bank, 2015b).

The remaining five countries all participated in the third season; the Cook Islands again paid its premium in full while each of the others increased its co-financing to fourteen per cent of the now $0.25 million premiums (Japan again covered the remainder). Tropical Cyclone Pam hit Vanuatu in March 2015, triggering a $1.9 million payout received by the government within a week of the event. While this provided critical short-term funding in accordance with the terms of the policy (equivalent to eight times Vanuatu's available emergency funds), the government was displeased with the small size of the payout relative to estimated total losses of $450 million (PCRAFI Program, 2018).

With the third and final pilot season ending and a successor mechanism uncertain, stakeholders opted to extend the project for an additional three years. Annual premiums for the 2015/2016, 2016/2017, and 2017/2018 seasons increased to $500,000. The Marshall Islands, Samoa, Tonga, and Vanuatu renewed their policies, with each paying $50,000 in 2015, $60,000 in 2016, and $70,000 in 2017 (the World Bank paid the remainder). The Cook Islands also renewed and paid its premiums in full.

In 2016, PIC governments marked the beginning of 'Phase II' of the project by establishing a new PCRAFI Facility in the Cook Islands as part of a 'phased handover' of responsibility from the World Bank to stakeholders (PCRAFI Program, 2018). The Facility consisted of two legal entities. The Pacific Catastrophe Risk Insurance Foundation (PCRIF) was managed by representatives of the five policyholders and the five donors to a new $40 million PCRAFI Multi-Donor Trust Fund (MDTF) (Canada, Germany, Japan, United Kingdom, and

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United States). In turn, PCRIF was the sole owner of the Pacific Catastrophe Risk Insurance Company (PCRIC), a member-owned insurer that replaced the World Bank as financial intermediary between participating countries and reinsurers. PCRIC was initially capitalized with $24 million from the MDTF and continues to build its reserves.

In 2018, Tropical Cyclone Gita made landfall on Tonga, resulting in a $3.5 million payout. Soon after, however, rainfall from an ineligible storm system combined with volcanic ash to produce acid rain in parts of Vanuatu. Frustration with the lack of a payout, together with lingering disappointment regarding the events of 2015, led the government to depart Phase II. As an alternative, Vanuatu secured a 'catastrophe deferred drawdown option' (Cat DDO) from the World Bank, providing for a low-interest loan contingent on a declaration of emergency (World Bank, 2018b).

In April 2020, Tonga was struck again, this time by Tropical Cyclone Harold, and received a $4.5 million payout (World Bank, 2020). This was the largest payout to date from PCRAFI. Phase II is scheduled to end in 2021.

The most important issue currently facing PCRAFI is its low participation rate. Climate risk pools depend on geographic and climatic variation among their members to diversify risk, which makes pools more financially secure and allows for lower premiums and/or expanded coverage. Yet over the course of its institutional lifetime PCRAFI has failed to significantly expand its membership, with only six out of 15 eligible countries having enrolled since program inception; in the view of experts, 'until now the participation is too low to fully actualize the cost benefits of risk pooling' in PCRAFI (Vyas et al., 2019).

Low participation reflects the relative novelty of insurance for PICs: 'Market-based catastrophe risk solutions are very new for the PICs and mark a major shift in the management of natural disasters, where PICs are moving from crisis responder relying heavily on donor support, to risk manager planning in advance and securing funding through market-based solutions' (World Bank, 2016a). Lack of familiarity with complex parametric contracts, the limits of business interruption insurance, and other aspects of risk transfer have together contributed to a problem of unmet expectations. The Solomon Islands expected payouts in 2013–2014 but did not receive them, while Vanuatu received a smaller-than-expected payout in 2015. Unmet expectations have driven departures from the scheme and deterred other PICs from joining (Martinez-Diaz et al., 2019).

Insurance as compensation?

Despite these problems, PICs participating in PCRAFI have received payouts on multiple occasions. Payouts from PCRAFI compensate policyholder governments in the event of tropical cyclones (or earthquakes/tsunamis) that meet specific criteria. Natural hazards of this sort are regarded as 'acts of God' insofar as they do not have anthropogenic causes. Yet to the extent that the frequency and/or intensity of 'natural' hazards are increased as a result of climate change, those responsible for climate change may be held accountable for that portion of losses and damages caused by anthropogenic GHGs. The politics of L&D largely revolve around calls for developed countries to compensate developing countries for harms resulting from the historically disproportionate share of emissions released by the former. In the present context, this begs the question, do PICs regard insurance payouts as an acceptable form of climate compensation?[6]

Ultimately this is an empirical question. Historically, PICs have addressed issues of L&D primarily through positions taken and advocated for by AOSIS at the United Nations Framework Convention on Climate Change (UNFCCC). While AOSIS speaks on behalf of small island and low-lying coastal developing states around the world, PIC officials generally regard the group as effective in representing Pacific regional positions on various aspects of climate policy (Schwebel, 2018). According to the most recent comprehensive statement by AOSIS on L&D:

> AOSIS has a long history of calling for the Convention process to address loss and damage to the adverse effects of climate change. As far back as 1991, when the UNFCCC itself was still being drafted, AOSIS proposed the establishment of an international insurance pool. The proposal consisted of a collective loss-sharing scheme to compensate victims of sea-level rise. The scheme was to be funded by mandatory contributions from industrialised countries based on GNP and on relative greenhouse gas (GHG) emissions, i.e. contributions to the fund would be based on ability to pay as well as responsibility for impacts. The basic concept of the 1991 AOSIS proposal is still valid. (AOSIS, 2019, p. 1)

This 1991 proposal plainly viewed insurance funded by developed countries as one acceptable form of compensation (Linnerooth-Bayer et al., 2003).

PICs have also collectively addressed the issue of L&D through the Pacific Islands Forum (PIF), the region's premier political organization (Williams and McDuie-Ra, 2018). The fundamental views of PIF and other regional bodies on climate change are laid out in their 2016 *Framework for Resilient Development in the Pacific* (FRDP), which urges partners to:

> [e]stablish a regional facility to assist governments in disaster and climate change risk financing, including insurance, in national sustainable development strategies and processes, and support their access to international financing and support. For example, the PCRAFI Disaster Risk Financing and Insurance Initiative, acknowledging that additional mechanisms or expanded facility is needed for climate change. (SPC et al., 2016, p. 17).

While the FRDP's institutional authors welcome insurance, they clearly do not regard the current version of PCRAFI as sufficient.

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In 2017, Tuvalu proposed a Pacific Islands Climate Change Insurance Facility (PICCIF) based on principles of parametric insurance (Tuvalu, 2017). Tuvalu distinguished PICCIF from PCRAFI by characterizing the latter as relevant to 'natural hazards' arising from natural variability, such that PCRAFI 'does not properly respond to the climate change impact needs of Pacific Island countries' (Tuvalu, 2017, p. 2). Tuvalu also distinguished insurance from compensation: 'Establishing a comprehensive Facility to address climate change impacts will significantly reduce the need to seek compensation measures in the longer future. If decisive steps are taken now to assist Pacific Island countries the need to seeking [sic] compensation will be diminished (Tuvalu, 2017, p. 5). While separating insurance from compensation, this formulation also suggests that they are at least partially substitutable. Promoted by Tuvalu, the PICCIF proposal was endorsed by PIF in 2018 and is currently being advanced by the Secretariat of the Pacific Regional Environment Programme (SPREP) and UN Environment (SPREP, 2019).

In the context of the 2018 Suva Expert Dialogue on L&D conducted under the UNFCCC, the government of Vanuatu argued that 'Loss and Damage finance is much more than insurance mechanisms, and although Vanuatu has benefitted from the PACRAFI [sic] Pacific Catastrophe Risk Assessment and Financing Initiative, we view this as a use of finance and not the sustainable source of finance that we have been calling for since 1991' (Republic of Vanuatu, 2018, p. 4). To qualify as sustainable finance, funding must be 'new and additional', that is, distinct from existing and committed climate funding streams (Republic of Vanuatu, 2018, p. 5). New 'Insurance premium subsidies at various levels' are one potential source of such finance (Republic of Vanuatu, 2018, p. 5).

In our view, consideration of these and similar statements by PICs and associated actors suggests that for them, although compensation cannot be reduced to insurance, insurance could serve as one acceptable form of compensation under two conditions: (1) if it were funded by *premium support* from developed countries, and (2) if it were *new and additional* to existing disaster risk insurance. This view aligns closely with what has recently been described as an 'evolving insurance narrative' in the L&D debate, in which the global collective understanding of risk transfer for climate impacts 'continues to evolve from solidarity-based humanitarian assistance to accountability for climate-attributed impacts' (Linnerooth-Bayer et al., 2019, p. 507). The greater the shift in this direction, the more insurance mechanisms may be said to play a 'curative', compensatory role in addressing climate harms (Schinko et al., 2019).

Does PCRAFI meet these conditions? As a practical matter, the coverage offered by PCRAFI would have been unaffordable if not for the premium support provided by developed countries. Over the seven seasons spanning the Pacific Catastrophe Risk Insurance Pilot and the PCRAFI Facility, premiums for all but one participating government were subsidized at a minimum level of 86 per cent (2014/2015) up to 100 per cent (2013) by members of the G7 and the World Bank (the exception was the high-income Cook Islands). According to Simon Young, an advisor and consultant to PCRAFI, PICs 'have always felt that insurance of the kind we are trying to develop should be paid for by the polluting countries' (Ferrie, 2018).

Yet PICs have made clear that, to qualify as compensation for harms from climate change, insurance must be new and additional to existing disaster risk insurance like PCRAFI.[7] Additionality in this sense has particular salience in the context of parametric insurance. Demonstrating causation plays no role in the functioning of this type of insurance. On one hand, this allows parametric insurance to bypass both the need for claims adjustment intrinsic to indemnity insurance and the need to delineate a causal chain inherent in legal liability (Horton, 2018). On the other, the inapplicability of causation means that parametric schemes by their nature are indifferent to why changes in index values take place. In practice, this means that no distinction is made between an event caused by natural variability and an event caused by anthropogenic climate change.

This has real-world implications, not least for funding, as evidenced by the discourse surrounding PCRAFI. Since its inception, PCRAFI has consistently articulated dual goals of DRM and climate adaptation; currently, PCRAFI describes itself as aiming 'to engage in a dialogue with the PICs on integrated financial solutions for the reduction of their financial vulnerability to natural disasters and to climate change' (PCRAFI, 2020). PICs, however, are uneasy with this formulation because they view it as creating a loophole for developed countries to relabel existing disaster assistance as new adaptation funding in order to meet their climate finance commitments. This explains the positions taken by PIF, Tuvalu, and Vanuatu discussed above, and it is why, for the region to accept insurance as a form of compensation for L&D, payouts need to be seen as additional to disaster risk reduction (DRR) funding streams.

Additionality would require increased tropical cyclone coverage to reflect the increased frequency and intensity of ENSO-mediated Pacific storm activity projected to occur under climate change, as well as new flood and drought policies to account for their similarly elevated risks; such policies have already been developed by other risk pools and are currently under consideration by PCRAFI (PCRAFI Program, 2018). Estimates for what such expanded coverage would cost are unavailable and difficult to calculate. Ordinarily, parametric schemes require long time series meteorological data to help determine which events qualify as extreme compared to historical baselines, but under elevated GHG levels, sophisticated regional climate modeling would be necessary. Accounting for climate change would add significant uncertainty and increase the risk load for insurers covering L&D. Thus, for PCRAFI to be regarded by PICs as compensatory would require expanded, more costly coverage paid for by developed countries.

Reduced-rate climate risk insurance for solar geoengineering (RCG) and the Pacific experience

The trajectory of PCRAFI, and Pacific politics more broadly, point to ways in which regional experience must shape the

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configuration of RCG if it is to be relevant for future policy in the Pacific. To repeat, RCG entails proposing states offering reduced-rate (RR) insurance to opposing states as an alternative to business-as-usual (BAU) insurance, on the condition that opposing states drop their objections to SG. Since opposing states are assumed to be better off with RR insurance regardless of whether SG works, they are incentivized to accept deployment.[8]

This scenario takes as given that BAU insurance is paid for by opposing states, which are implicitly assumed to be *poor or middle-income countries*. As we have seen, however, in the Pacific region, the expectation is that baseline CRI (equivalent to BAU insurance under RCG) is paid for by *developed countries*. Unsubsidized CRI would be unacceptable to PICs. From their perspective, CRI subsidies from industrialized countries would reflect a combination of ODA for natural disasters (unrelated to climate change) and compensation for climate harms (potentially in the form of enhanced adaptation financing). Hence, RCG would only be relevant to the Pacific if the current regional regime of limited tropical cyclone (and earthquake/tsunami) business interruption insurance for PIC governments subsidized by donor countries, namely, PCRAFI, were transformed into a future regime of similarly supported but expanded and more costly coverage for tropical cyclones as well as floods and droughts.

At least two pathways building on existing initiatives are conceivable. First, PCRAFI itself could be upgraded. As noted in the previous section, PCRAFI is currently considering supplementing its offerings with flood and drought coverage; it is also exploring the possibility of offering products tailored to individual PICs, for example, household insurance for Fiji (Ramachandran and Masood, 2019).[9] These moves are intended to address regional demand for a broader suite of insurance products, which it is hoped will result in greater participation by PICs in PCRAFI and hence more effective risk pooling. To the extent that membership in PCRAFI has been limited due to unmet expectations grounded in a lack of familiarity with (parametric) insurance, however, more experience and expanded stakeholder engagement may be more likely to help increase penetration. Given that additional coverage for tropical cyclones, floods, and droughts under climate change may be significantly more costly, in part due to greater uncertainty and higher risk loads, it is crucial that participation in PCRAFI is increased in order to diversify risks and reduce costs.

Second, the PICCIF proposal championed by Tuvalu is conceived as specifically targeting regional risks attributable to climate change. As noted, PICCIF is currently being formulated with support from SPREP and UNEP, and details are not publicly available. Depending on its final form and the reception it receives from PICs and potential donors, PICCIF could represent a route toward subsidized CRI for the Pacific.

Funding is flowing into CRI at the global level. At the 2019 UN Climate Action Summit in New York, pledges of approximately $500 million and $100 million by Germany and the UK, respectively, for global CRI were accompanied by a re/insurance industry commitment to provide up to $5 billion in risk capacity for twenty developing countries by 2025 (BMZ et al., 2019). These commitments were in addition to the more than half billion dollars previously pledged by G20 countries to the central InsuResilience Global Partnership (Horton, 2018).

It is unclear whether climate insurance in the Pacific will evolve toward something like comprehensive CRI. On the one hand, less than a decade ago no regional risk pool existed in the Pacific, yet today PCRIC is capitalized at nearly $25 million, PICs have received more than $10 million in payouts, and there is interest in and funding to support further expansion. On the other hand, coverage is limited, participation remains low, pledges may not materialize, and future commitments (particularly in the aftermath of the global COVID-19 pandemic) may not be forthcoming.

If comprehensive CRI were available in the Pacific, would the use of SG create any climate risks that fall outside its scope of coverage? As discussed earlier, the most serious concerns about SG articulated by Pacific regional stakeholders so far pertain to ignorance, caution, moral hazard, lock-in, exclusion, and uncertainty. These concerns are general in nature, and because they are not quantifiable in the way required by insurance, they are not amenable to coverage. Yet these concerns are the product of preliminary discussions and are likely to evolve following more sustained engagement. At the level of governments, where evidence suggests the 'logic of consequences' overrides the 'logic of appropriateness' (Krasner, 1999), it is likely that risks related to the possible climate impacts of SG will play a greater role in policy decisions. As noted in the introduction, researchers have paid most attention to potential SG impacts tied to regional hydrological changes that may cause floods and droughts. If PIC governments prove to be most concerned with potential material damages related to the effects of deployment on weather and climate, then they are likely to view floods and droughts as the most salient risks. Since PICs would expect CRI to include expanded flood and drought coverage, an upgraded version of PCRAFI or newly introduced PICCIF would in theory be sufficient to address risks from SG. (Relatedly, since the levels of uncertainty associated with outcomes under climate change and SG are comparable, there would be no prima facie reason for the price of CRI to increase following deployment – see note 1.)

For RCG to be relevant to the Pacific, then, BAU insurance would need to be subsidized by industrialized countries. Most likely, some of these countries would advocate for SG deployment while others would oppose it. The former would be confident in the technology, expect implementation to reduce both climate risks and insurance rates, and anticipate the avoided costs from lower premiums to result in savings. To succeed in deployment, however, industrialized advocates would need to persuade states resistant to SG to stand aside. Resistant states would likely include both other industrialized countries and some developing countries, in this case PICs.

To convince skeptical industrialized countries, industrialized advocates confident in SG ought to be willing to

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assume all financial responsibility for premium support above the (lower) rates they expect to follow from implementation of the technology. This is different from offering RR insurance: rather than proposing to initiate premium support, industrialized advocates would offer to take on an increasing share of the future costs otherwise expected to fall on industrialized skeptics subsidizing BAU insurance. From the perspective of advocates, this would amount to a virtually costless overture to skeptics that could overcome barriers to deployment. From the perspective of skeptics, accepting this overture would ensure them cost savings no matter how SG turned out; depending on the scale of anticipated cost savings, this could be a strong incentive to accept SG.

To convince PICs opposed to SG, industrialized advocates could pledge to pass on their own anticipated cost savings to subsidized policyholders. Again, this is different from offering RR insurance: advocates would offer to supplement their existing support for BAU insurance with additional transfers. From the perspective of PICs hostile to SG, these transfers would represent side payments on top of the compensation for SG risks they would already be assured via subsidized CRI, along with the possibility of reduced climate risks including curtailed sea level rise. From the advocate perspective, foregone cost savings may be a price worth paying to gain consent from PICs.

Industrialized country advocates could thus offer benefits to both skeptical industrialized countries and PICs in return for their consent to deploy. Ultimately, consent from industrialized skeptics would be more consequential than consent from PICs. RCG is partly based on the presumption that unilateral deployment of SG is unlikely (Horton and Keith, 2019). If a state or group of states were to implement SG against the wishes of other countries, those opposed would likely retaliate via some combination of trade and/or financial sanctions, institutional exclusion, and other means short of military action but entailing high political and economic costs. Compared to the long-term, uncertain, and globally dispersed benefits of SG, knowledge of the immediate, certain, and concentrated costs triggered by unilateral deployment would likely deter states tempted to implement SG outside of a multilateral framework.

RCG is concerned with overcoming such deterrence by creating a more appealing alternative to retaliation. Efforts to overcome deterrence must focus on those actors that make deterrence credible. Credible deterrence of unilateral deployment depends on opposition from countries powerful enough to impose meaningful costs on those states considering unsanctioned implementation. Industrialized countries are much more likely than PICs to possess the capabilities necessary to bring states inclined toward SG to the negotiating table. Since industrialized skeptics will hold the most effective veto power over unilateral deployment, they are likely to command the most attention from proposing states.

Exploring a possible bargain between industrialized countries divided over deployment aligns with the evolving international politics of SG, which is characterized by a growing split between the United States, relatively open to the technology, and a European Union that is more cautious. This transatlantic disagreement recently manifested at the 2019 meeting of the UN Environment Assembly, where conflicts over a draft resolution on geoengineering technology assessment ultimately forced its withdrawal (Jinnah and Nicholson, 2019). If this divide becomes more entrenched, the theoretical reconfigurations suggested here will shed valuable light on the strategic political situation.

Thus, considering RCG in the context of the Pacific has the effect of shifting the analytical focus away from bargaining between developed and developing countries and toward bargaining between developed countries themselves. This change is significant but limited insofar as it pertains specifically to revisions required for RCG to be relevant to the Pacific region. Other regions have differing experiences, understandings, and expectations regarding CRI, L&D, and climate policy (and will have different views on SG), such that insights from the Pacific cannot simply be extrapolated to the global level. For example, in contrast to PICs and PCRAFI, African states have a tradition of self-financing their risk pool membership (Martinez-Diaz et al., 2019). A comprehensive assessment of RCG would necessarily entail, at a minimum, probing its plausibility in the context of other regional risk pools in Africa, the Caribbean, and potentially Southeast Asia, and synthesizing the resulting findings.[10.]

Industrialized country skeptics deciding whether to accept SG deployment would therefore have to consider, in addition to the prospect of guaranteed insurance cost savings tied to the Pacific, particularities associated with other regional contexts. Beyond this, industrialized skeptics would obviously take into account prospective climate damage to their own countries with and without SG, as well as broader economic, security, and normative factors. Similarly, industrialized advocates deciding whether to commit to cover their skeptical counterparts' catastrophic loss obligations in the Pacific would also need to consider the specific attributes of other regions and risk pools, the costs of SG deployment, their own climate risks with and without SG, and above all their confidence in the technology. And poor and middle-income countries would have to take a comparable range of factors and relationships into account when formulating their views. The net effect of these considerations is to turn a choice situation initially reducible to two actors – proposing and opposing states – facing a narrow set of possible outcomes into a more complex assemblage of interlinked games with multiple actors, multiple settings, and (presumably) multiple equilibria. As a consequence, additional work on RCG will likely require the use of more formal methods.

Conclusion

Taking seriously the Pacific view that compensatory climate insurance must be both supported by developed countries and additional to disaster risk insurance means that, for RCG to be relevant to the region, it must focus primarily on relations among developed countries. Such a reformulation

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presents challenges insofar as it rests on widespread support for CRI from industrialized states, but it also aligns more closely with underlying political realities and thus has more potential to work if preconditions are met. To the extent that negotiations over RCG would help clarify positions for and against SG deployment, even unsuccessful talks would be a valuable means of increasing transparency and enhancing mutual understanding.

Of course, as noted above, insights derived from an analysis of the Pacific may not be applicable to other regions. Further, apart from insights specific to the Pacific context, more general aspects of RCG remain oversimplified compared to real-world politics. Countries, whether industrialized, middle-income, or poor, are unlikely to be either for or against SG deployment; instead they will all probably have more complicated and nuanced positions regarding the technology that fail to correspond precisely with conventional geopolitical and ideological categories. Likewise, parametric insurance schemes can rarely be satisfactorily characterized as either disaster risk insurance for events stemming from natural variability or CRI pertaining to harms from anthropogenic climate change; instead their boundaries are fuzzy, as evidenced by the discourse surrounding PCRAFI. And parametric insurance itself can be difficult to differentiate from other index-based disaster risk finance instruments such as catastrophe bonds or shock-responsive social protection systems (Clarke and Dercon, 2016).

Nevertheless, constructs like RCG, suitably informed by practical experience, can be invaluable in teasing out bases for international cooperation or paths toward political resolution. SG has already given rise to significant disagreements, and climate policy more broadly is beset by failures. It is in this context that we consider RCG to have considerable potential for clarifying concerns about SG in a way that also speaks, however imperfectly, to concerns about justice.

Notes

1. It is important to note that the scientific literature offers no evidence to suggest that the uncertainty of climate prediction under SG would be any greater than that under GHG-driven climate change.
2. The term PICs is used here following the standard convention to refer to all sovereign states in the Pacific region except for Australia and New Zealand, plus two countries formally in free association with New Zealand – the Cook Islands and Niue – that operate autonomously.
3. AOSIS is the acronym for the Alliance of Small Island States, an intergovernmental organization representing the interests of small island developing states in global climate policy.
4. Such co-financing, or 'counterpart commitments', is longstanding World Bank practice, based on the notion that contributions by recipient countries promote a sense of project commitment and ownership and ultimately result in more effective development support.
5. The Cook Islands receives no premium support because, unlike other PICs, it is considered a high-income developed country by the Organisation for Economic Cooperation and Development and other international bodies.
6. Note that, following the Paris Agreement, the term 'compensation' has come to be regarded as 'taboo' (Calliari, Surminski, & Mysiak, 2018: 173) within the UNFCCC due to its historically close association with the concept of liability, which was explicitly excluded as a basis for addressing L&D at Paris (Horton, 2018). Nevertheless, the basic concept of compensation – financial payment for harm made on the basis of accountability – persists as a central feature of discussions on L&D, although it is now frequently articulated using alternative formulations.
7. Indeed, while PICs have tended to equate PCRAFI with disaster risk insurance unproblematically in L&D and other forums, its nature as business interruption insurance means that truly comprehensive disaster risk insurance would need to cover a wider range of disaster losses.
8. This assumption depends on SG operating within some well understood system distribution such that a suboptimal performance remains within the confidence interval of the statistical model used to develop the insurance scheme. If SG produces an outcome that is much worse than expected, then states would be worse off even with RR insurance. Quantifying the probability of 'failure' is at the heart of how RCG operationalizes divergent judgments about SG outcomes.
9. Fiji joined PCRAFI in 2018 to become eligible.
10. Some Southeast Asian states are considering forming a sovereign parametric climate insurance scheme known as the Southeast Asia Disaster Risk Insurance Facility, or SEADRIF.

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